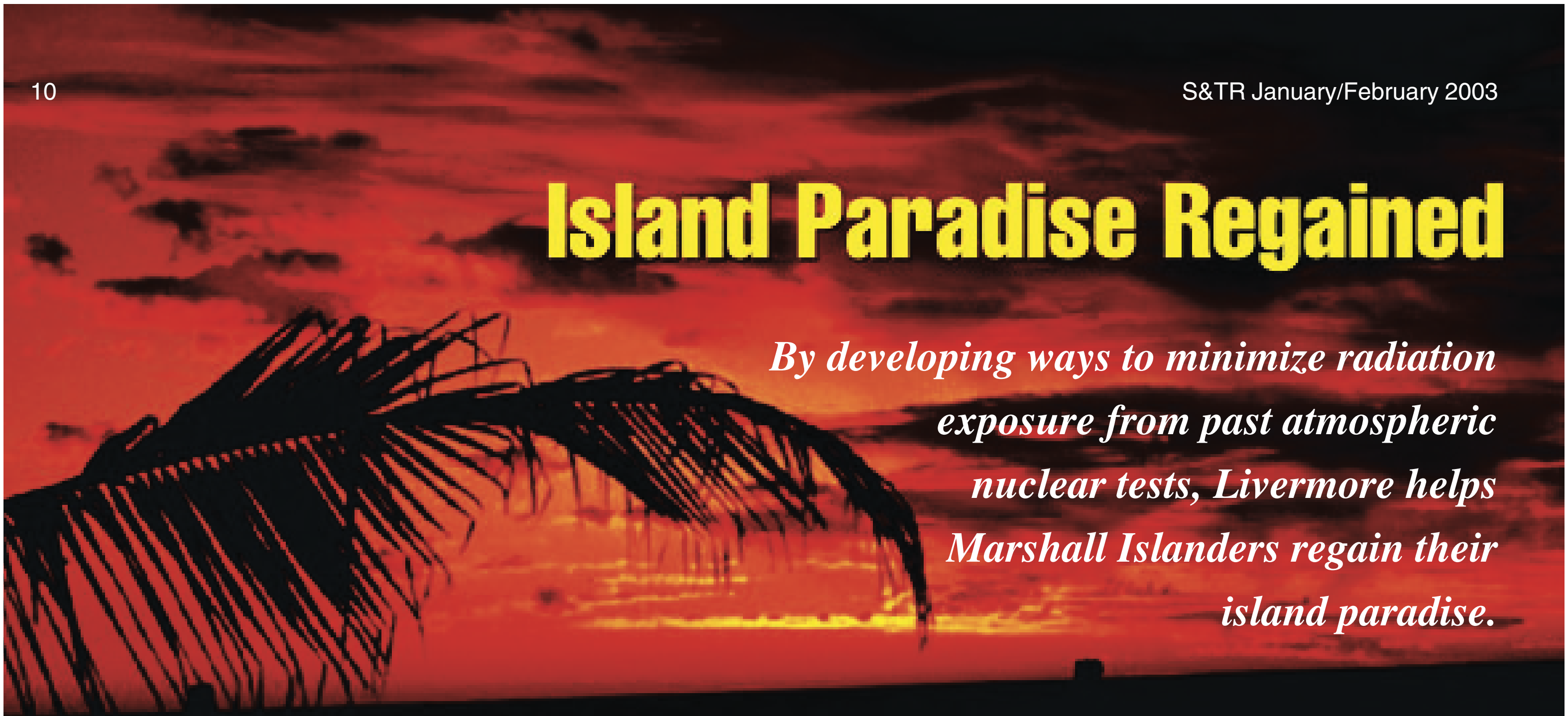


Island Paradise Regained

By developing ways to minimize radiation exposure from past atmospheric nuclear tests, Livermore helps Marshall Islanders regain their island paradise.

BETWEEN 1945 and 1958, the United States conducted 67 atmospheric tests of nuclear weapon designs on the Bikini and Enewetak atolls of the Marshall Islands. After this testing ended in the late 1950s, residents who had been relocated from these atolls began asking to return to their home islands.

But going home proved to be not so simple. At Enewetak, for instance, islands continued to be used for other defense programs through the 1960s and 1970s. Finally, in 1978, an extensive radiological survey was conducted of the northern Marshall Islands, including those in the Bikini and Enewetak atolls. An aerial survey determined the external gamma exposure rate. Samples of soil, food crops, animals, well water, seawater, fish, and more were collected to evaluate the radionuclide concentrations in the atoll environment. About the same time, the U.S. launched a massive cleanup and rehabilitation program on the Enewetak Atoll, scraping off about 76,400 cubic meters of surface soil from 6 islands and sealing it off in a crater on the atoll's Runit Island.

This cleanup focused primarily on removing and containing plutonium and other heavy radioactive elements from a group of islands in the northwest corner of the atoll where most of the tests were conducted and the highest levels of local fallout were found. Yet, even during this early cleanup, questions arose about whether these efforts would be adequate to protect the returning Enewetak population. Predictive assessments based on the extensive radiological survey showed that ingestion of cesium-137 and other fission products from eating locally grown food and drinking the local water was the most significant exposure pathway. Cesium-137 fallout from the tests was more widely distributed than plutonium.

Islanders and scientists had already had an opportunity to discover what happened when islands were resettled without adequately addressing the ingestion portion of the equation. In 1969, the people of Bikini had resettled their home islands. Once the locally planted food crops had matured and island residents began including the resulting fruits in their diet, the amount of cesium-137 in their bodies (the "body burden") increased dramatically. The people of Bikini once again had to leave their islands and have yet to return.

The southern portion of the Enewetak Atoll was resettled in 1980. Today, scientists in Lawrence Livermore's Marshall Islands Dose Assessment and Radioecology Program work to minimize exposure through ingestion and other pathways for the Marshallese now living on or wishing to return to their islands. The program, directed by Livermore environmental scientist Terry Hamilton, continues research begun nearly 30 years ago—characterizing radiological conditions on affected islands and developing strategies to minimize radiological exposure to a people wishing to resettle. The program also supports Marshallese efforts to implement radiation protection programs for residents wishing to track their exposure to radionuclides from fallout contamination that still lingers on the islands.

Doing the Groundwork

When islanders from Bikini and Enewetak—and, later, Rongelap—began asking questions about residual fallout contamination on their islands, U.S. officials decided that more knowledge of the conditions of the atolls was needed before resettlement could begin. (See box on p. 17.) Livermore scientists conducted large-scale environmental surveys of the radionuclide distribution to gather data for analyzing the health risks the island residents might face if they resettled. Questions to answer included: What would be the long-term radioactive exposure from eating crops grown on the islands? From drinking the water? From eating fish caught in the lagoons?

For more than 25 years, Livermore scientists have collected over 70,000 samples of edible food crops, vegetation, soil, water, marine life, and animals to evaluate the various exposure pathways for radiological dose. They combined the radionuclide inventory from the samples, a diet model for the population, and biokinetic models to determine the dose due to ingestion. (See *S&TR*, January/February 1997, pp. 14–21.) At several atolls, they also evaluated external exposure to gamma radiation and studied how the resumption of human activity might cause nuclides in the surface soil to be resuspended in the air and thus inhaled. Results indicated that ingestion was the most significant exposure pathway, with external exposure to gamma radiation being the next most significant. The dose from ingestion contributed 70 to 90 percent of the dose to island residents, mostly through uptake of cesium-137 into island-grown foods such as coconut, pandanus, breadfruit, and papaya.

"One of the most significant things we discovered from this research is that the uptake of cesium-137 is very different for plants grown in Marshall Islands soils than for plants grown in North American and European soils," says Hamilton. The uptake of cesium-137 in continental soils—the measurement used in most previous studies—is much lower. Such uptake can be expressed by the soil-to-plant transfer factor, that is the ratio of becquerels (units of radioactive activity) per kilogram of dry weight plant to becquerels per kilogram of dry weight soil. For cesium-137, the soil-to-plant transfer factors for tropical fruits grown on Bikini range between 2 and 40; for vegetation grown on continental soils in temperate zones, the factors range between 0.005 and 0.5. The reason for the difference lies in the different compositions of the soils.

Unlike continental soils, island coral soils have little clay and low concentrations of potassium. With no clay for the cesium to bind to and plants essentially starving for potassium, the plants take up cesium as a replacement for the potassium. "Once we knew this, we could more reliably predict the dose for returning residents and develop a strategy to limit the availability and uptake of cesium-137 into the crops," says Hamilton.

Among the methods considered was removing contaminated soil that contains most of the cesium-137. However, the surface soil layer supplies all the nutrients for plants and controls the amount of water held in the soil. Removing this top layer wholesale would lead to severe environmental effects and a long-term commitment to rebuild the soil and revegetate an island.

Livermore's environmental scientists continue work begun more than a quarter century ago in the Marshall Islands, assessing and evaluating the various exposure pathways for radiological dose and developing ways to limit the dose. (a) Experiments to reduce the uptake of cesium-137 by coconut trees and other food crops have been conducted on Bikini Island. (b) Fish collected on annual sampling trips are analyzed for radionuclides at Livermore.

After examining other methods for eliminating cesium from the soil or reducing its uptake into food crops, the team settled on a remediation technique of applying potassium fertilizer and using limited soil removal in housing and village areas. It developed this method on results of large-scale field experiments conducted by Livermore on Bikini Island. The added potassium reduces the cesium-137 taken up by plants by nearly 90 percent, lowering the associated ingestion dose to about 5 to 10 percent of the pretreatment levels. The fertilizer has an added benefit as well—supporting the growth and increasing the productivity of the plants.

In 2000, when activities began to prepare Rongelap Island for resettlement planned for 2003, scientists took the agricultural fix developed on Bikini and combined it with a procedure designed to reduce external exposure rates and inhalation or ingestion of contaminated soil containing plutonium. This procedure involves removing surface soil down to about 25 centimeters in and around the housing and village areas and replacing it with crushed coral. A detailed in situ gamma radiation survey of the entire area, conducted during May 2001 by Livermore scientists, found that the average external dose from cesium-137 within the service and village areas was reduced by more than 20-fold to less than 1 millirem a year. To put this dose in perspective, the average person in the U.S. receives a dose of about 46 millirems per year from natural terrestrial gamma radiation.

Plates inserted into soil collect water that will help scientists determine the removal rate of radionuclides due to rainfall. One area of current research in the Marshall Islands involves determining the environmental factors that remove radionuclides from the immediate environment. For instance, rainfall is leeching cesium-137 from the soil into the groundwater and out into the lagoons. Scientists are discovering that this process is actually more important than radiological decay in decreasing the dose over time.

The results of the fertilization work on Rongelap are still pending, although the data from monitoring resettlement workers suggest that internal doses from cesium-137 ingestion in the resettled population will be extremely low. "In this case," says Hamilton, "the use of potassium will, we hope, provide an added assurance to the people that the island is suitable for resettlement."

Hamilton added that, for the islanders who return, the situation should only improve with time. Rainfall transports cesium-137 out of the root zone of plants and into the groundwater. In the longer term, this will reduce cesium-137 levels in local food crops and reduce dose estimates even further. Livermore researchers are now exploring how long the beneficial effects of a single potassium treatment lasts and evaluating the rate of environmental loss of cesium-137 in the atoll ecosystem as a whole.

Determining Each Person's Dose

Another goal of the Livermore effort is developing individual radiation protection programs that ensure doses to island residents remain at or below acceptable safety standards. The cornerstone of this activity rests on whole-body counting systems and a new Livermore-developed technique to measure extremely small amounts of plutonium in urine.

Whole-body counting systems measure the gamma rays coming from radionuclides such as cesium-137, cobalt-60, and potassium-40 deposited in the body and internal organs. The total amount of a radionuclide measured in this manner is converted into a dose estimate using specially designed commercial software. Hamilton explains that the main pathway for exposure to residual fallout contamination in the northern Marshall Islands is through ingestion of cesium-137, and whole-body counting is a simple and effective method for determining the quantity of cesium-137 taken up by an individual. "This part of the program offers island residents an unprecedented level of radiation protection monitoring," he adds. "With these systems in place, residents don't have to rely on assumptions made about their intake of locally grown foods. They get real measurements on a person-by-person basis." When measurements are combined with environmental monitoring data, individuals can make informed decisions about eating habits and lifestyle.

Local Marshallese technicians trained at Lawrence Livermore operate whole-body counting facilities on Rongelap and Enewetak. Livermore scientists provide technical assistance and advanced training and perform detailed quality assurance appraisals on the data before they are released.

Plutonium urinalysis is a sensitive measurement technique for estimating a person's exposure to plutonium. Urine is collected from an individual over a 24-hour period and turned into a powder that scientists analyze by counting the number of plutonium atoms in a sample. "All of us have a small amount of plutonium in our bodies from exposure to worldwide

Fallout from History

The story of fallout and its repercussions in the Marshall Islands can be summed up by looking at events in three of the northern atolls—Bikini, Enewetak, and Rongelap.

Soon after World War II ended, the United States examined several possible locations for conducting tests for its growing nuclear weapons program. The coral atolls in the northern Marshall Islands in the Pacific Ocean appeared to offer the best advantages of stable weather conditions, fewest inhabitants to relocate, isolation, and—with hundreds of miles of open ocean to the west—minimum radioactive fallout onto populated areas. Residents were relocated from islands in the Bikini and Enewetak atolls before testing began.

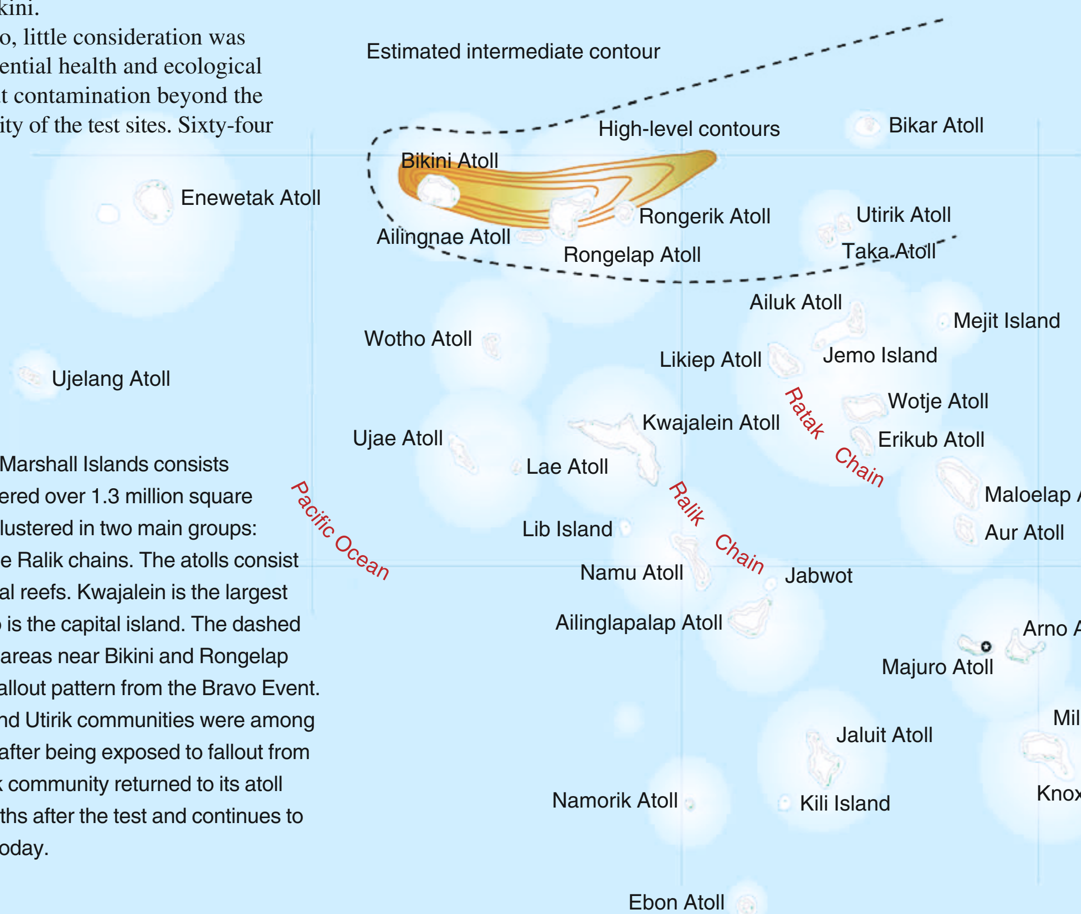
The most significant contaminating nuclear test conducted in the Marshall Islands was the Castle–Bravo Event on March 1, 1954. The explosive yield of Bravo exceeded expectations and resulted in unexpected radioactive fallout over the inhabited islands of the Rongelap and Utitrik atolls and other areas east of Bikini.

Before Bravo, little consideration was given to the potential health and ecological effects of fallout contamination beyond the immediate vicinity of the test sites. Sixty-four people on Rongelap received significant exposure from Bravo and had to be evacuated for medical treatment. The Rongelap community spent the next three years living on Ejit Island in the Majuro Atoll before returning home in 1957.

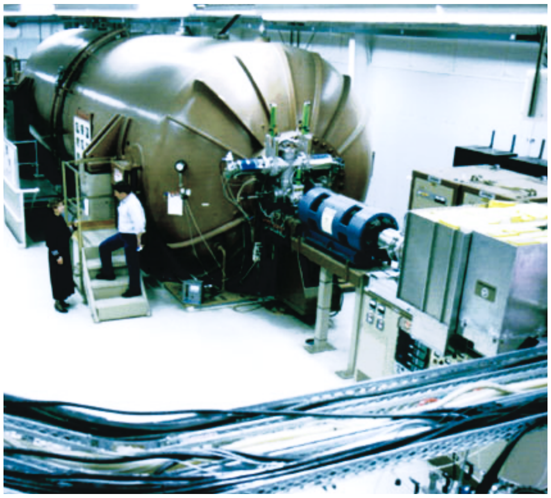
Rongelap was the first atoll to experience an early wave of resettlement. Bikini was next, with islanders settling on their homelands in 1969, planting food crops, and returning to their island lifestyle. But trouble bloomed in paradise. Once the planted food crops in Bikini matured and started to produce fruit, the fruit became part of the inhabitants' diets, and the amount of cesium-137 in the Bikini residents' bodies increased dramatically. In 1978, the people of Bikini left their islands a second time. A similar turn of events occurred in Rongelap, where growing concerns about the possible health effects of exposure to residual fallout contamination prompted residents to relocate again in 1985. The Rongelap community continued to express a strong desire to return. In 1996, the U.S. Congress approved a resettlement agreement that included an initiative to reduce the level of radiation exposure on the island using a cleanup strategy developed by Livermore scientists.

As for Enewetak, it continued to be used for defense programs until cleanup began in 1977. The southern part of Enewetak was successfully resettled in 1980, and islanders continue to live there. From 1980 to 1997, scientists from Brookhaven National Laboratory periodically monitored the resettled population for internally deposited radionuclides, a program that then moved under the purview of Lawrence Livermore.

The work on the Marshall Islands continues, with Livermore playing a number of key roles, including characterizing the radiological conditions at the various atolls; determining the transport, uptake, and cycling of radionuclides in the ecosystem; and estimating the potential radiological doses and risk.



The Republic of Marshall Islands consists of 34 atolls scattered over 1.3 million square kilometers and clustered in two main groups: the Ratak and the Ralik chains. The atolls consist of numerous coral reefs. Kwajalein is the largest atoll, and Majuro is the capital island. The dashed line and shaded areas near Bikini and Rongelap atolls show the fallout pattern from the Bravo Event. The Rongelap and Utirik communities were among those relocated after being exposed to fallout from Bravo. The Utirik community returned to its atoll about three months after the test and continues to inhabit the atoll today.



Livermore's new technology to measure extremely small amounts of plutonium isotopes and other long-lived radioisotopes came out of research conducted at the Center for Accelerator Mass Spectrometry. This sensitive measurement technique has possible applications beyond the Marshall Islands work, in areas such as nuclear isotopic forensics and counterterrorism, risk assessments, and dose reconstruction for exposed nuclear workers.

Marshallese technicians trained at Livermore run whole-body counting facilities on Rongelap and Enewetak. The facility at Enewetak is shown below in the background.

fallout contamination," notes Hamilton. "The Livermore team's job is to compare the amount of plutonium detected in Marshall Islands residents with that seen elsewhere to assess likely intakes associated with resettlement."

Plutonium urinalysis can detect extremely small amounts of plutonium. The technique, developed at Livermore's Center for Accelerator Mass Spectrometry as part of a Laboratory Directed Research and Development project, is about a hundred times more sensitive than techniques used in U.S. occupational monitoring programs. Data from the studies show that residents' and island workers' exposures to plutonium are low. "People get a higher dose of radiation taking an airplane from the Bay Area to one of these islands than they get while working there," says Hamilton.

A recent comparison exercise organized by the National Institute of Standards and Technology for determining low-levels of plutonium in synthetic urine gave high marks to the mass spectroscopy technique. In fact, Livermore's laboratory was the only one to meet the American National Standards Institute (ANSI) quality performance criteria for both precision and bias at all test levels.

Over the past three years, memorandums of understanding between the U.S. Department of Energy, the Republic of the Marshall Islands, and the Enewetak–Ujelang and Rongelap Local Atoll Government have been signed, leading to the design and construction of radiological laboratories on Enewetak and Rongelap atolls. A third facility is slated for construction in 2003 on the capital island of Majuro and will be available to residents of Utirik and other outlying islands.

Going Home

"In the Marshall Islands, societal fear of radiation conflicts with a desire to resettle native homelands," concludes Hamilton. "The work the Livermore team is doing—providing environmental measurement data and dose assessments—has the goal of finding ways to minimize the exposures of returning residents. First, there is the remediation. Then there's whole-body counting and the accelerator mass spectrometry measurements. As communities return and settle into these islands, we hope that the programs will provide a level of reassurance to the residents that the amount of radiation they receive is small—well below the standards set by their own government—and becoming smaller."

—Ann Parker

Key Words: accelerator mass spectrometry, Bikini Atoll, Bravo Event, Center for Accelerator Mass Spectrometry (CAMS), cesium-137, dose assessment, Enewetak Atoll, Marshall Islands resettlement, Nuclear Test Program, plutonium, Rongelap Atoll, whole-body counting.

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